CHAPTER 7

HIGH AND LOW ENERGY SCRUBBER SYSTEMS

7-1. Scrubbers

A scrubber utilizes a liquid to separate particulate or gaseous contaminants from gas. Separation is achieved through mass contact of the liquid and gas. Boiler emissions to be controlled include fly ash and sulfur oxides. Incinerator emissions to be controlled include fly ash, sulfur oxides and hydrogen chloride.

7-2. Types of scrubbers

a. Low energy scrubbers. Low energy scrubbers are more efficient at gaseous removal than at particulate removal. A low energy scrubber utilizes a long liquid-gas contact time to promote mass transfer of gas. Low energy scrubbers depend on extended contact surface or interface between the gas and liquid streams to allow collection of particulate or gaseous emissions.

(1) *Plate-type scrubbers.* A plate-type scrubber consists of a hollow vertical tower with one or more plates (trays) mounted transversely in the tower (figure 7-1). Gas comes in at the bottom of the tower; and must pass through perforations, valves, slots, or other openings in each plate before exiting from the top. Liquid is usually introduced at the top plate, and flows successively across each plate as it moves downward to the liquid exit at the bottom. Gas passing through the openings in each plate mixes with the liquid flowing over the plate. The gas and liquid contact allows the mass transfer or particle removal for which the plate scrubber was designed. Plate-type scrubbers have the ability to remove gaseous pollutants to any desired concentration provided a sufficient number of plates are used. They can also be used for particle collection with several sieve (perforated) plates combining to form a sieve-plate tower. In some designs, impingement baffles are placed a short distance above each perforation on a sieve plate, forming an impingement plate upon which particles are collected. The impingement baffles are below the level of liquid on the perforated plates and for this reason are continuously washed clean of collected particles. Particle collection efficiency is good for particles larger than one mircron in diameter. Design pressure drop is about 1.5 inches of water for each plate.

(2) *Preformed spray scrubbers.* A preformed spray scrubber (spray tower) is a device which collects particles or gases on liquid droplets and utilizes spray nozzles for liquid droplet atomization (figure 7-2). The sprays are directed into a chamber suitably shaped to conduct the gas through the atomized liquid droplets. Spray towers are designed for low pressure drop and high liquid consumption. They are the least expensive method for achieving gas absorption because of their simplicity of construction with few internals. The operating power cost is low because of the low gas pressure drop. Spray towers are most applicable to the removal of gases which have high liquid solubilities. Particle collection efficiency is good for particles larger than several microns in diameter. Pressure drops range from 1 to 6 inches, water gauge.

(3) *Centrifugal scrubbers.* Centrifugal scrubbers are cylindrical in shape, and impart a spinning motion to the gas passing through them. The spin may come from introducing gases to the scrubber tangentially or by directing the gas stream against stationary swirl vanes (figure 7-2). More often, sprays are directed through the rotating gas stream to catch particles by impaction upon the spray drops. Sprays can be directed outward from a central spray manifold or inward from the collector walls. Spray nozzles mounted on the wall are more easily serviced when made accessible from the outside of the scrubber. Centrifugal scrubbers are used for both gas absorption and particle collection and operate with a pressure drop ranging from 3 to 8 inches, water gauge. They are inefficient for the collection of particles less than one or two microns in diameter.

(4) *Impingement and entrainment scrubbers.* Impingement and entrainment scrubbers employ a shell which holds liquid (figure 7-3). Gas introduced into a scrubber is directed over the surface of the liquid and atomizes some of the liquid into droplets. These droplets act as the particle collection and gas absorption surfaces. Impingement and entrainment scrubbers are most

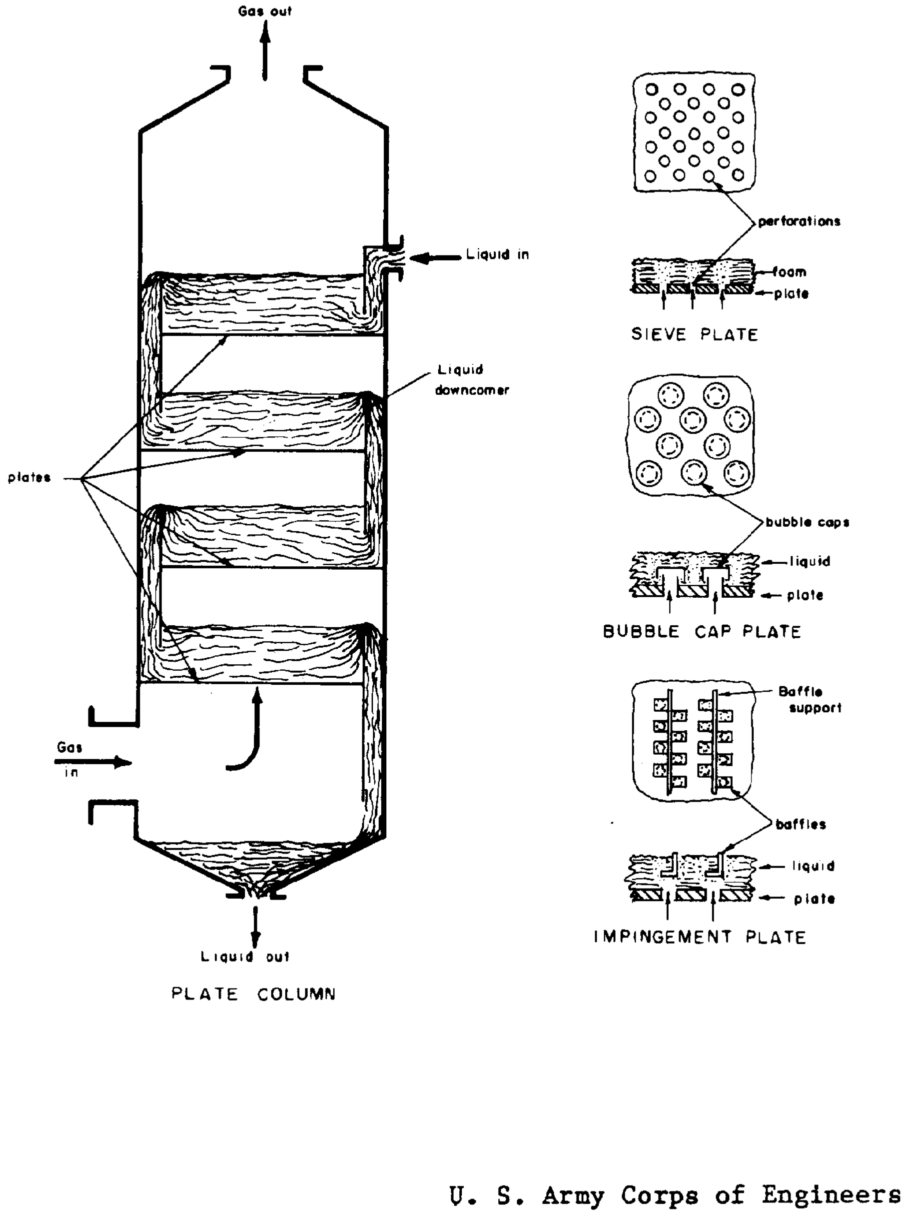

Figure 7–1. Plate type scrubber

frequently used for particle collection of particles larger than several microns in diameter. Pressure drops range from 4 to 20 inches, water gauge.

(5) *Moving bed scrubbers.* Moving bed scrubbers provide a zone of mobile packing consisting of plastic, glass, or marble spheres where gas and liquid can mix intimately (figure 7-3). A cylindrical shell holds a perforated plate on which the movable packing is placed. Gas passes upward through the perforated plate and/or down over the top of the moving bed. Gas velocities are sufficient to move the packing material when the scrubber is operating which aids in making the bed turbulent and keeps the packing elements clean. Moving bed scrubbers are used for particle collection and gas absorption when both processes must be carried out simultaneously. Particle collection efficiency can be good down to particle sizes of one micron. Gas absorption and particulate collection are both enhanced when several moving bed stages are used in series. Pressure drops range from 2.5 to 6 inches water gauge per stage.

b. High energy scrubbers. High energy scrubbers utilize high gas velocities to promote removal of particles down to sub-micron size. Gas absorption efficiencies are not very good because of the co-current movements of gas and liquid and resulting limited gas/liquid contact time.

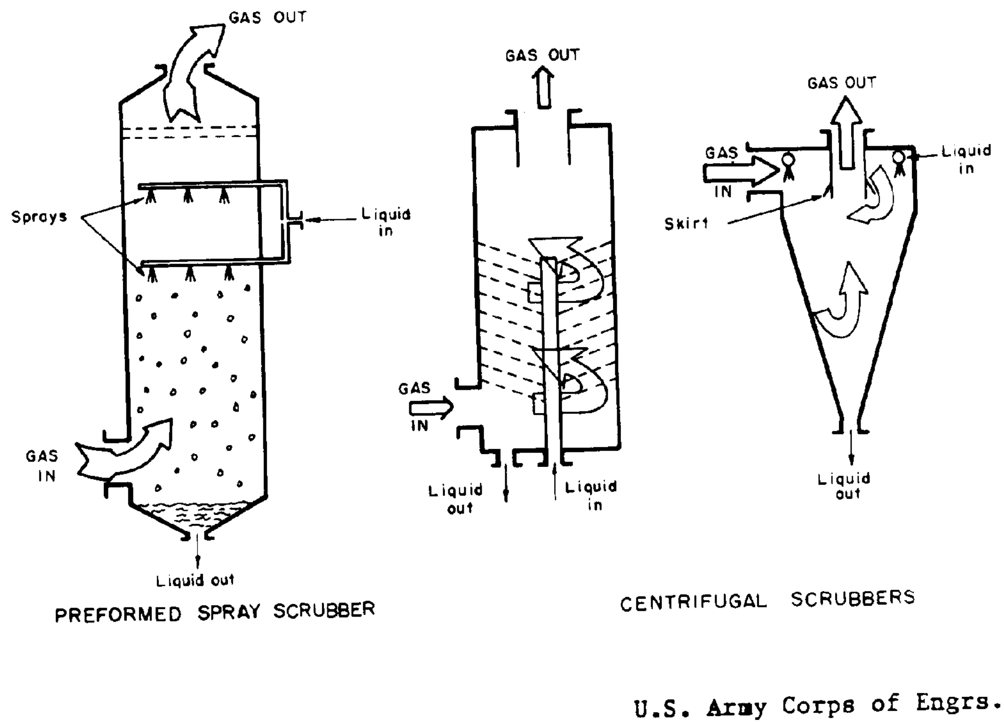

Figure 7–2. Types of spray and centrifugal scrubbers

(1) *Venturi scrubbers.* The venturi scrubber utilizes a moving gas stream to atomize and accelerate the liquid droplets (figure 7-4). A convergent-divergent nozzle is used to achieve a gas velocity of 200 to 600 feet per second (ft/ sec) which enhances liquid atomization and particulate capture. Collection efficiency in a gas atomized venturi scrubber increases with pressure drop. Pressure drops of 25 inches water gauge or higher are utilized to collect sub-micron particles. Scrubbers of the gas atomized type have the advantage of adjustment of pressure drop and collection efficiency by varying gas velocity. The gas velocity is controlled by adjusting the area of the venturi throat. Several possible methods for doing this are illustrated in figure 7-5. This can be used to control performance under varying gas flow rates by maintaining a constant pressure drop across the venturi throat. Due to the absence of moving parts, scrubbers of this type may be especially suitable for the collection of sticky particles. Disadvantages include high pressure drop for the collection of sub-micron particles and limited applicability for gas absorption.

(2) *Ejector venturi.* The ejector venturi scrubber utilizes a high pressure spray to collect particles and move the gas. High relative velocity between drops and gas aids in particle collection. Particle collection efficiency is good for particles larger than a micron in diameter. Gas absorption efficiency is low because of the co-current nature of the gas and liquid flow. Liquid pumping power requirements are high and capacity is low making this type impractical for boiler or incinerator emissions control.

(3) *Dynamic (wetted fan) scrubber* This scrubber combines a preformed spray, packed bed or centrifugal scrubber with an integral fan to move the gas stream through the scrubber. Liquid is also sprayed into the fan inlet where the rotor shears the liquid into dispersed droplets. The turbulence in the fan increases liquid/ gas contact. This type of scrubber is effective in collection of fine particulate. Construction of this scrubber is more complex due to the necessity of the fan operating in a wet and possibly corrosive gas stream. The design must prevent build-up of particulates on the fan rotor.

c. Dry scrubbers. Dry scrubbers are so named because the collected gas contaminants are in a dry form.

(1) *Spray dryer.* The spray dryer is used to remove gaseous contaminants, particularly sulfur oxides from the gas stream. An alkaline reagent slurry is mechanically atomized in the gas stream. The sulfur oxides react with the slurry droplets and are absorbed into the droplets. At the same time,

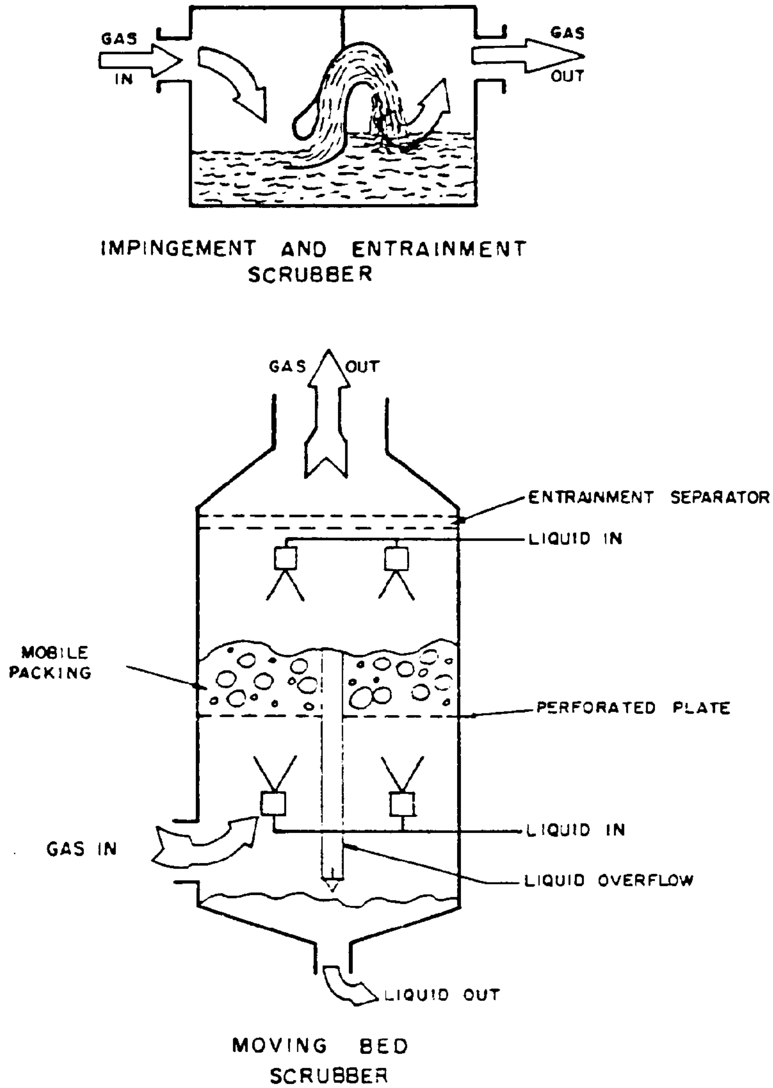

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Figure 7–3. Types of entrainment and moving bed scrubbers

the heat in the gas stream evaporates the water from the droplets leaving a dry powder. The gas stream is then passed through a fabric filter or electrostatic precipitator where the dry product and any fly ash particulate is removed. The scrubber chamber is an open vessel with no internals other than the mechanical slurry atomizer nozzles. The vessel is large enough to allow complete drying of the spray before impinging on the walls and to allow enough residence time for the chemical reaction to go to completion. A schematic of the system is shown in figure 7-6. Refer to chapters 8 and 9 for discussion of the fabric filter or electrostatic precipitator.

(2) *Gravel bed.* The gravel bed, while referred to as a dry scrubber, is more a filter using sized gravel as the filter media. A bed of gravel is contained in a vertical cylinder between two slotted screens. As the gas passes through the interstices of the gravel, particulates impact on, and are collected on the gravel surface. Sub-micron size particles are also collected on the surface because of their Brownian movement. Dust-laden gravel is drawn off the bottom and the dust is separated from the gravel by a mechanical vibrator or pneumatic separator. The cleaned gravel is then conveyed up and dumped on top of the gravel bed. The cylindrical bed slowly moves down and is constantly recycled.

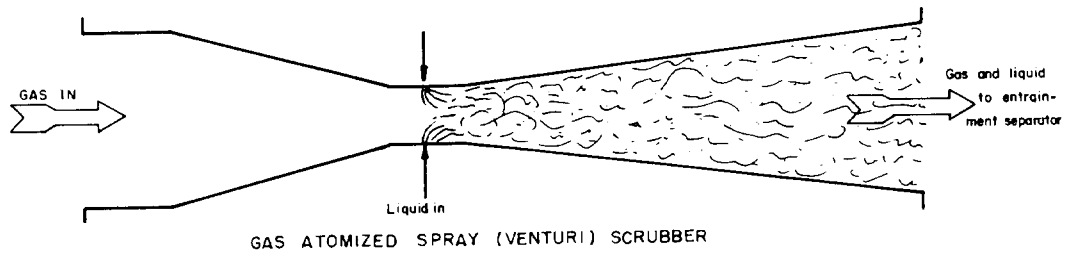

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Figure 7–4. Gas atomized spray (venturi) scrubber

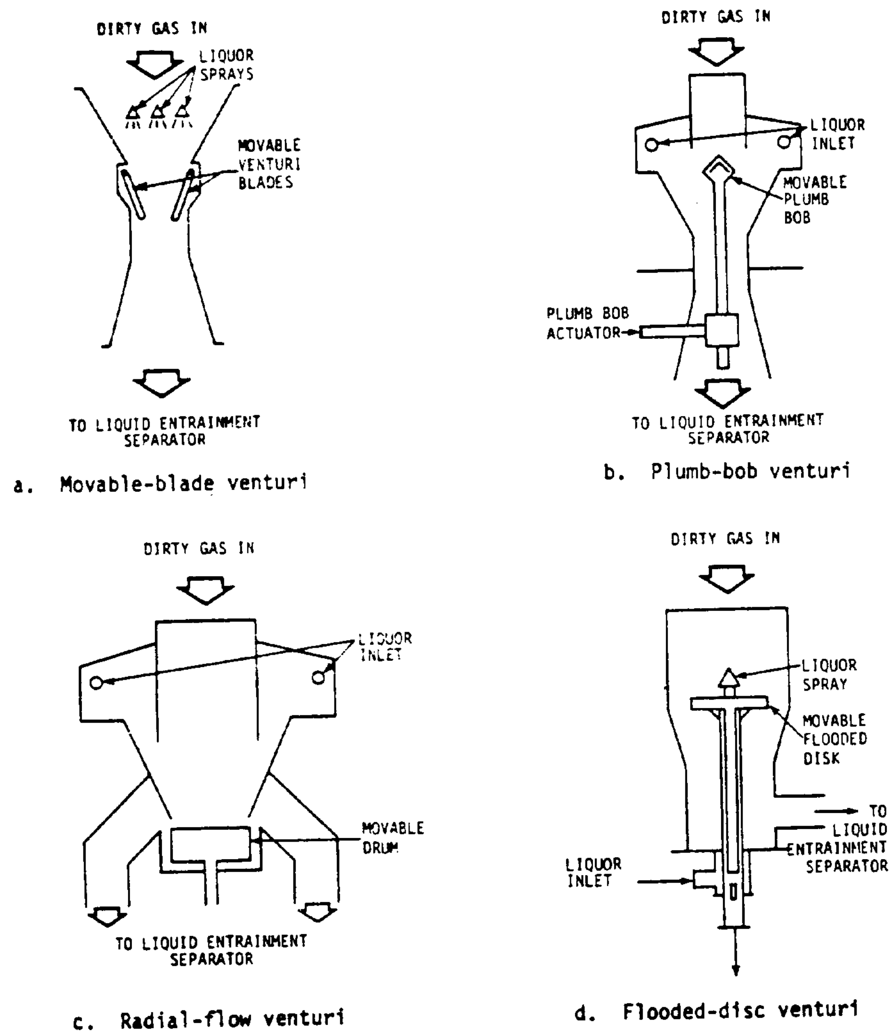

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Figure 7–5. Throat sections of variable venturi scrubbers

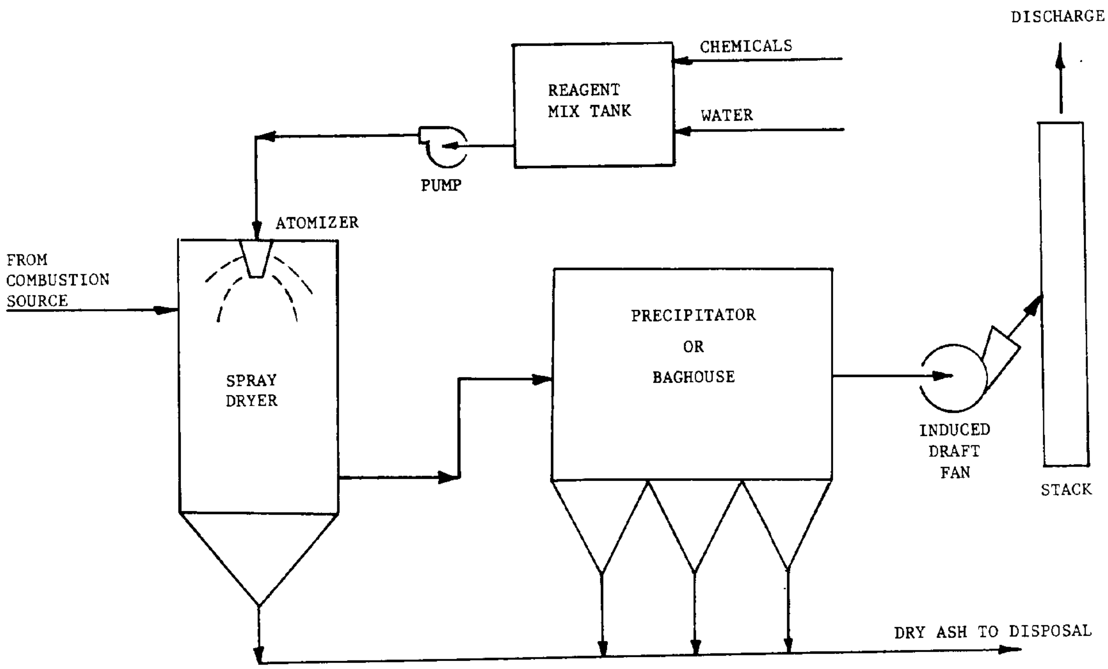

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Figure 7–6. Spray dryer system

7-3. Application

a. Particulate removal. Scrubbers may be used as control devices on incinerators and boilers for fly ash collection. The plate, spray, venturi, and moving bed types have been successfully applied; however, their application has been limited because they require:

— more energy than dry particulate collection devices of the same collection efficiency,
— water supply and recovery system,
— more extensive solid waste disposal system,
— system to control the scrubbing process in response to gas flow rate changes.

b. In making decisions on applicability to a particular process, figure 7-7 is useful in determining all components which must be taken into consideration.

c. Gaseous removal. Scrubbers have been used primarily for the removal of sulfur oxides in stack gases. (See chapter 10 for a more detailed description of sulfur oxides (SO_x) control techniques.) However, as new control systems are devised, simultaneous removal of gases and particulate material will become the accepted procedure for designing scrubbers for combustion processes.

7-4. Treatment and disposal of waste materials

Wet scrubber systems are designed to process exhaust streams by transfer of pollutants to some liquid medium, usually water seeded with the appropriate reactants. Liquid effluent treatment and disposal are therefore an essential part of every wet scrubber system. Installation and maintenance of the associated components can add appreciably to the system capital and operating costs. The degree of treatment required will depend upon the methods of disposal or recycle and on existing regulations. Required effluent quality, environmental constraints, and availability of disposal sites must be established before design of a treatment facility or the determination of a disposal technique can proceed. In many industrial applications the scrubber liquid wastes are combined with other plant wastes for treatment in a central facility. Design of this waste treatment should be by an engineer experienced in industrial waste treatment and disposal.

7-5. Selection of materials

a. General conditions. When choosing construction materials for scrubber systems, certain pertinent operating parameters should be considered. The metal surface of an exhaust gas or pollution control system will behave very differently in the same acid mist environment, depending on conditions of carrier gas velocity, temperature, whether the conditions are reducing or oxidizing, and upon the presence of impurities. For example, the presence of ferric or cupric iron traces in acids can dramatically reduce corrosion rates of stainless steels and titanium alloys. On the other hand, traces of chloride or fluoride in sulfuric acid can cause

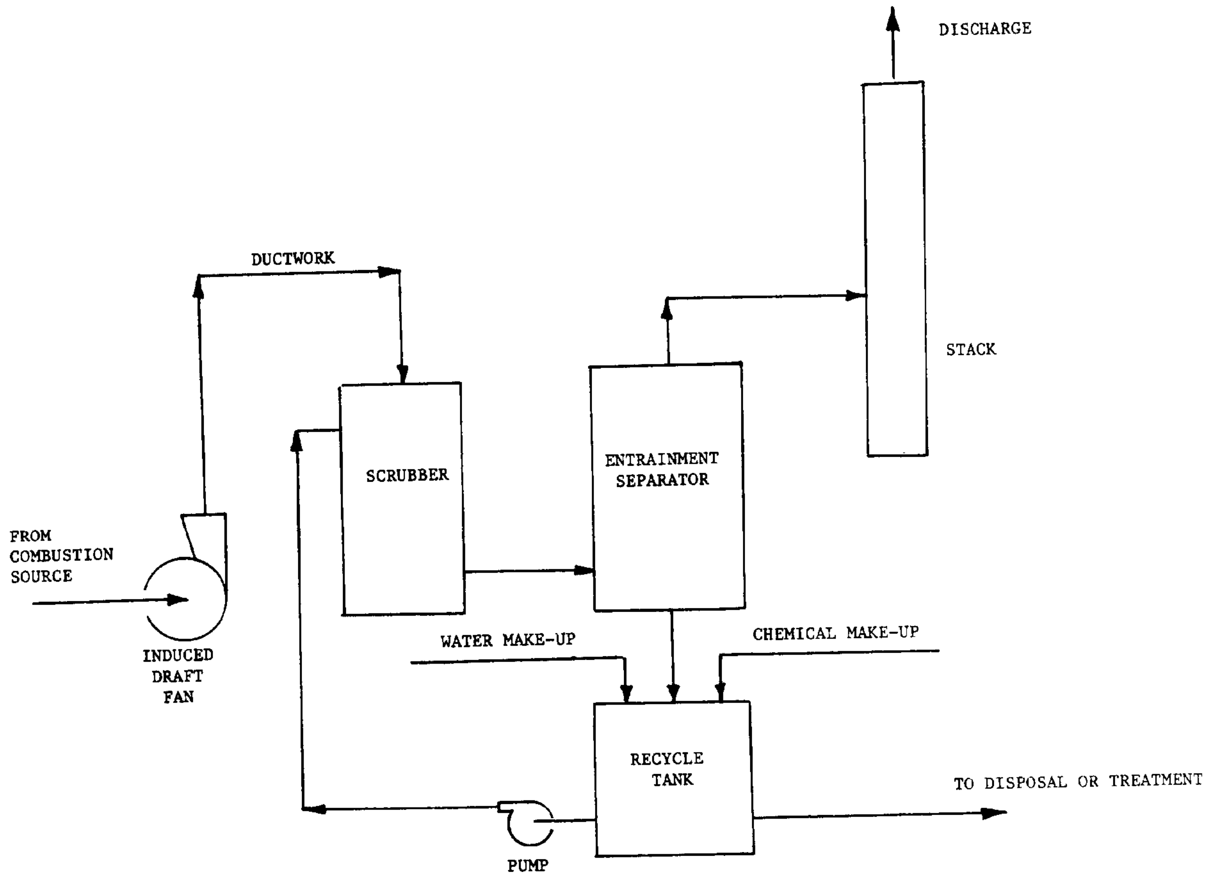

Figure 7–7. Schematic diagram of scrubber flow

severe pitting in stainless steels. This condition is frequently encountered in an incinerator which burns large quantities of disposable polyvinyl chloride (PVC) materials.

b. Temperature. Corrosion rates generally increase with increases in exhaust temperatures. This is due to the increased mobility of ions and increased reaction rates. However, in cases where the corrosion process is accelerated by the presence of oxygen, increasing the acid temperature eventually boils out dissolved oxygen, rapidly diminishing corrosion rate. This is the case with Monel, a nickel-copper alloy.

c. Velocity. Often the corrosion resistance of an alloy depends on the existence of an adhering oxide layer on its surface. A high exhaust gas velocity can remove or erode the surface layer. Once removed, this layer cannot be renewed because the oxide film is washed away as it forms.

d. State of oxidation. Under reducing condition, Monel is very resistant to moderate sulfuric-acid concentrations. Under oxidizing conditions, or in the presence of oxidizing ions, however, very rapid corrosion occurs. The reverse is true of stainless steels which are resistant to oxidizing acid environments, but are attached by acids under reducing conditions. The equipment designer should select materials based on individual case conditions including temperature, abrasion, pH, etc.

7-6. Auxiliary equipment

a. Gas transport.

(1) *Ducts and stacks.* Large boiler plant stacks have a wind shield of reinforced concrete or of steel, with a separate inner flue or numerous flues of steel, acid-resistant brick, and occasionally, stainless steel. The space between the inner flue and the outer wind shield may be insulated with a mineral wool wrapping. This is to prevent the condensation of acid dew on the inside of the metal chimney, which occurs below dew point temperature, and also to prevent acid “smut” from being blown out of the chimney. Acid smut is a term for ash particles contaminated with acid. It is heavy and tends to fall out of the gas plume soon after exiting from the

stack. In smaller plants, stacks may be a single wall steel construction with insulation and lagging on the outer surface. For wet scrubbing practice, chimneys for vapor-saturated gases containing corrosive substances may be made of rubber-lined steel, fiberglass-reinforced resin or other corrosion-resistant material. With materials that have a limited maximum temperature, provisions must be made to protect the stack from high temperatures because of loss of scrubbing liquid. Chimney or stack velocities are generally 30 ft/ sec to prevent re-entrainment of moisture from the stack wall which would rain down around the plant. Sometimes cones are fitted at the top to give exit velocities as high as 75 ft/sec. The chief reason for high velocities is to eject the gases well away from the top of the stack to increase the effective height and to avoid downwash. Downwash can damage the metal structure supporting the stack, the stack itself, or the outside steel of a lined metal stack. (For a more detailed analysis of the meteorological considerations involved in stack design, see chapter 4.)

(2) *Fans.* In a wet scrubber system the preferred location for the boiler or incinerator induced-draft fan is upstream of the scrubber. This eliminates the need for special corrosion-resistant construction required to handle the wet downstream gas. The fan should be selected to resist build-up of dry ash or erosion of the rotor surfaces. For high dust load applications a radial blade or radial tip blade fan is more durable. In a dry scrubber application the fan should be downstream of the scrubber in the clean gas stream. Here a more efficient air-foil or squirrel-cage rotor can be used.

b. Liquid transport.

(1) *Pipework.* For most scrubbing duties, the liquid to be conveyed will be corrosive. There exists a wide variety of acid resistant pipework to choose from, but generally speaking, rubber-lined steel pipe has high versatility. It is easy to support, has the strength of steel, will withstand increases in temperature for a short time and will not disintegrate from vibration or liquid hammer. Fiberglass filament wound plastic pipe is also suitable for a very wide range of conditions of temperature, pressure, and chemicals. The chief disadvantage of rubber-lined pipe is that it cannot be cut to size and has to be precisely manufactured with correct lengths and flange drilling. Site fabrication is not possible. Most piping is manufactured to ANSI specifications for pressure piping. Considerations must also be made for weatherproofing against freezing conditions.

(2) *Pumps.* Centrifugal pumps are used to supply the scrubbing liquid or recycled slurry to the scrubber nozzles at the required volume flow rate and pressure. Where no solids are present in the liquid, bare metal pumps, either iron or stainless steel construction, are used. In recycle systems with solids in the liquid, special rubber-lined or hard-iron alloy pumps are used to control erosion of the pump internals. These are generally belt driven to allow selection of the proper speed necessary for the design capacity and head. Solids content must still be controlled to limit the maximum slurry consistency to meet the scrubber and pump requirements.

c. Entrainment separation. After the wetted gas stream leaves the scrubbing section, entrained liquid droplets must be removed. Otherwise they would rain out of the stack and fall on the surrounding area. Removal can be by gravity separation in an expanded vessel with lowered velocity or a cyclonic separator can swirl out the droplets against the vessel wall. Knitted wire or plastic mesh demisters or chevron or “zig-zag” vanes can be located at the scrubber outlet to catch any droplets.

d. Process measurement and control. The scrubber control system should be designed to follow variations in the boiler or incinerator gas flow and contaminant load to maintain outlet emissions in compliance with selected criteria.

(1) *Measurements.* Measurement of data from the process to provide proper control should include inlet gas flow rate, temperature and pressure, scrubber gas pressure drop, liquid pressure, flow rate, solids consistency, pH, and outlet gas temperature. Selection of instrumentation hardware should be on an individual application basis.

(2) *Control.* Pressure drop across a scrubber can be referenced as an indication of performance following initial or periodic, outlet gas testing. In a variable throat venturi, for instance, this pressure drop can be used to control the throat opening, maintaining constant performance under varying gas volume flow rates. Measurement of scrubber slurry solids consistency can be used to control bleed-off of high solids slurry and make-up with fresh water. If sulfur dioxide (SO_2) is being controlled then measurement of scrubber liquid pH can control make-up of caustic to maintain efficiency of SO_2 removal. Complete specification or design of a control system must be on a case-by-case basis.

7-7. Advantages and disadvantages

a. Advantages. The advantages of selecting scrubbers over other collection devices are:

— Capability of gas absorption for removal of harmful and dangerous gases,

— High efficiency of particulate removal,

— Capability of quenching high temperature exhaust gases,

— Capability of controlling heavy particulate loadings,

b. Disadvantages. The disadvantages of selecting scrubbers over other collection devices are:

— Large energy usage for high collection efficiency,

— High maintenance costs,

— Continuous expenses for chemicals to remove gaseous materials,

— Water supply and disposal requirements,

— Exhaust gas reheat may be necessary to maintain plume dispersion,

— Weather proofing is necessary to prevent freezeup of equipment.